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Proctor, Jr.

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(54) **ANTENNA CONTROL SYSTEM AND METHOD**

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(52) **U.S. Cl.**
USPC **370/342**; 370/335; 455/69; 455/522; 455/562.1

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See application file for complete search history.

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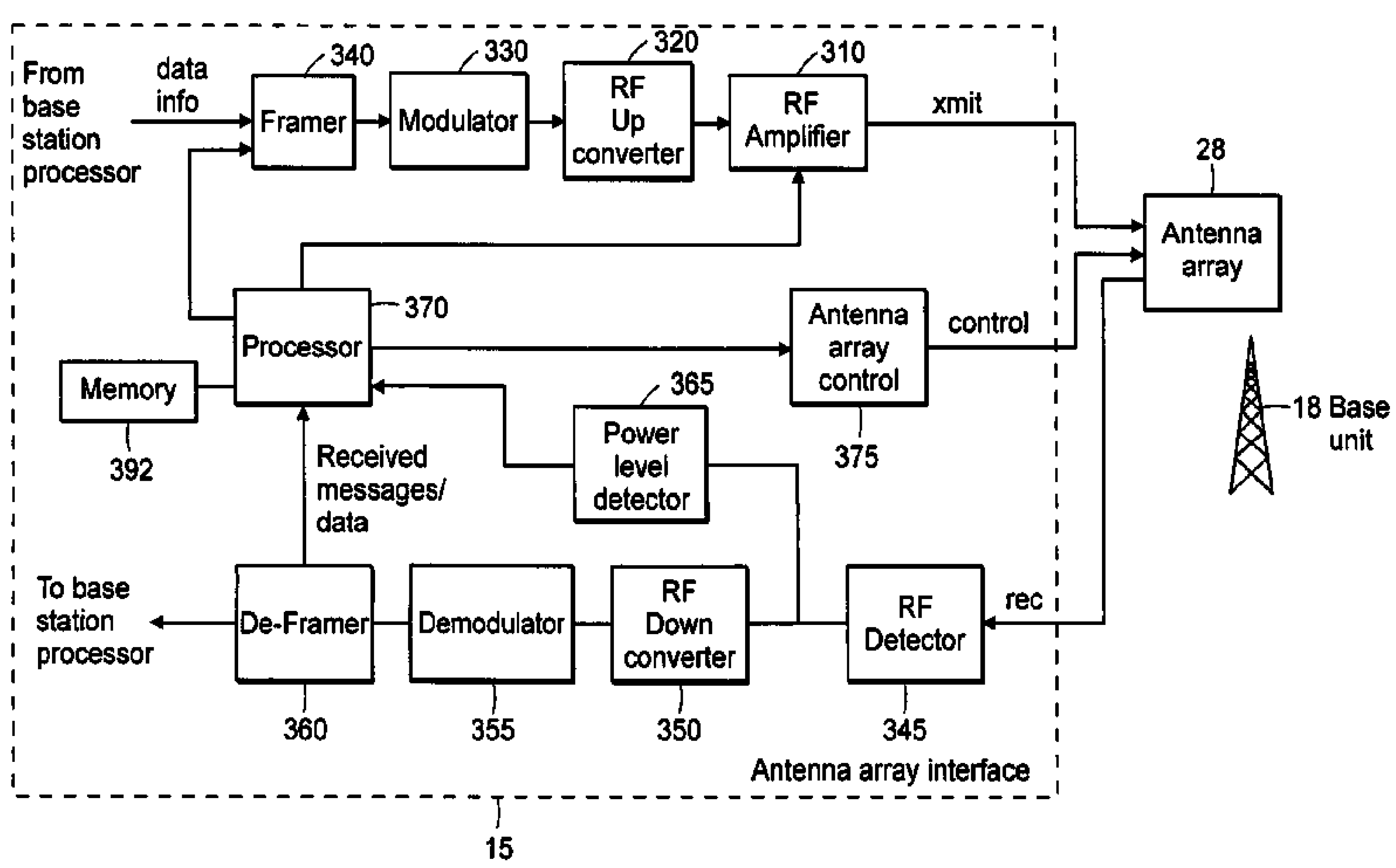
(57) **ABSTRACT**

A subscriber unit, including an antenna array and an antenna array interface coupled to the antenna array, is described. Wireless transmissions, at least two of which are based on different directional transmissions from a transmitter, are received at the antenna array. Feedback messages are generated using the antenna array interface. The feedback messages are communicated using the antenna array to adjust settings of the transmitter.

7 Claims, 5 Drawing Sheets



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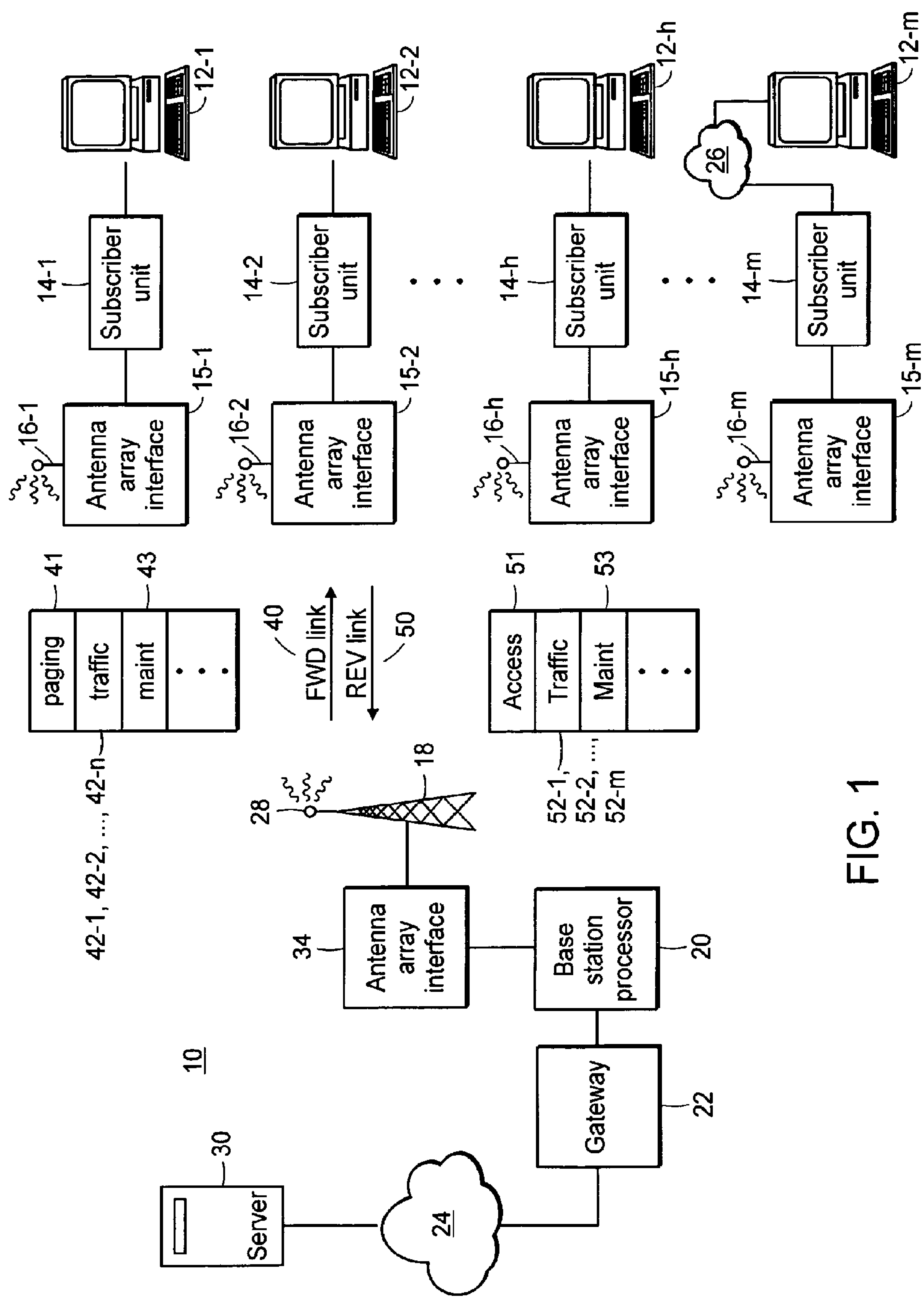
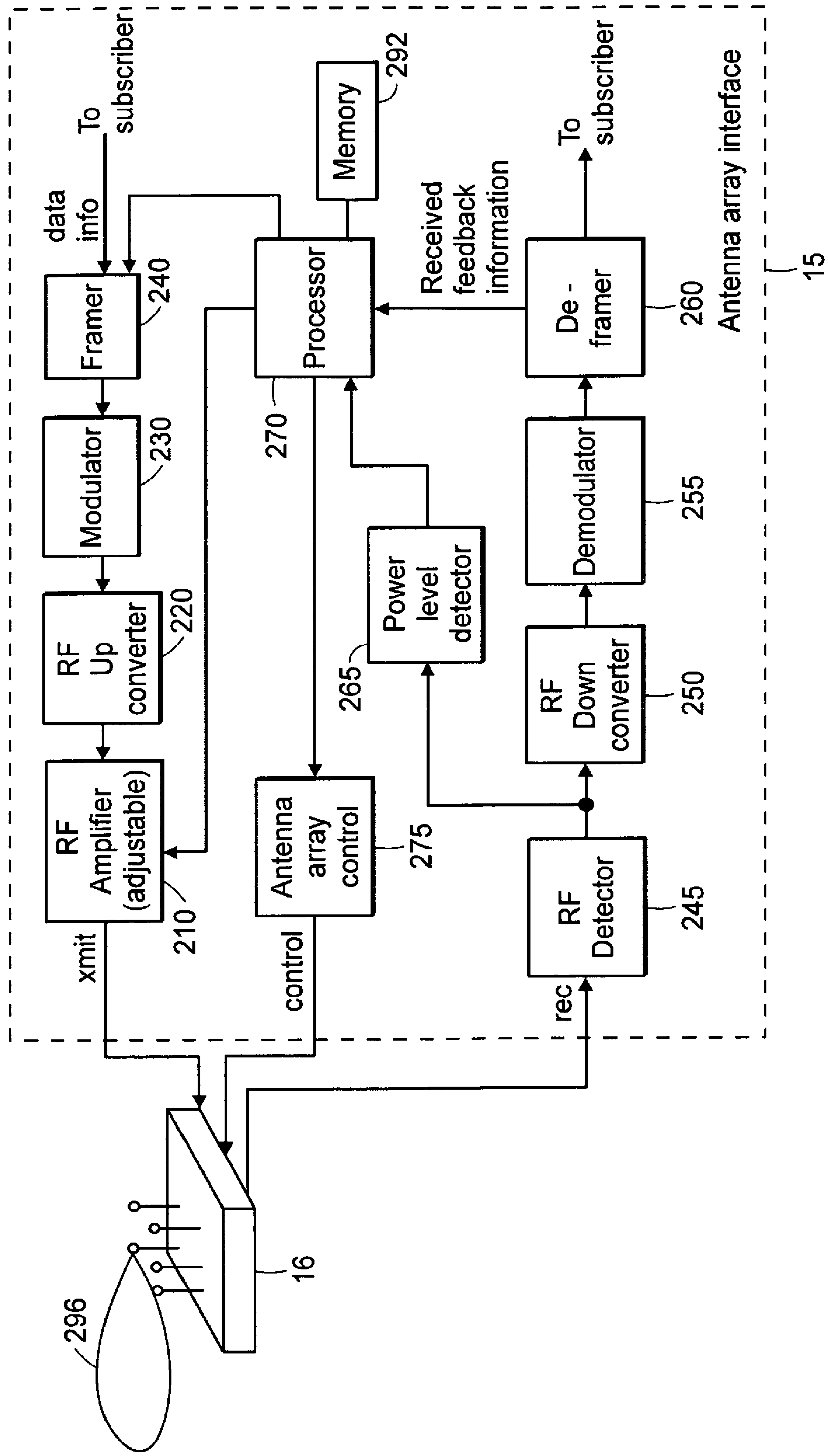
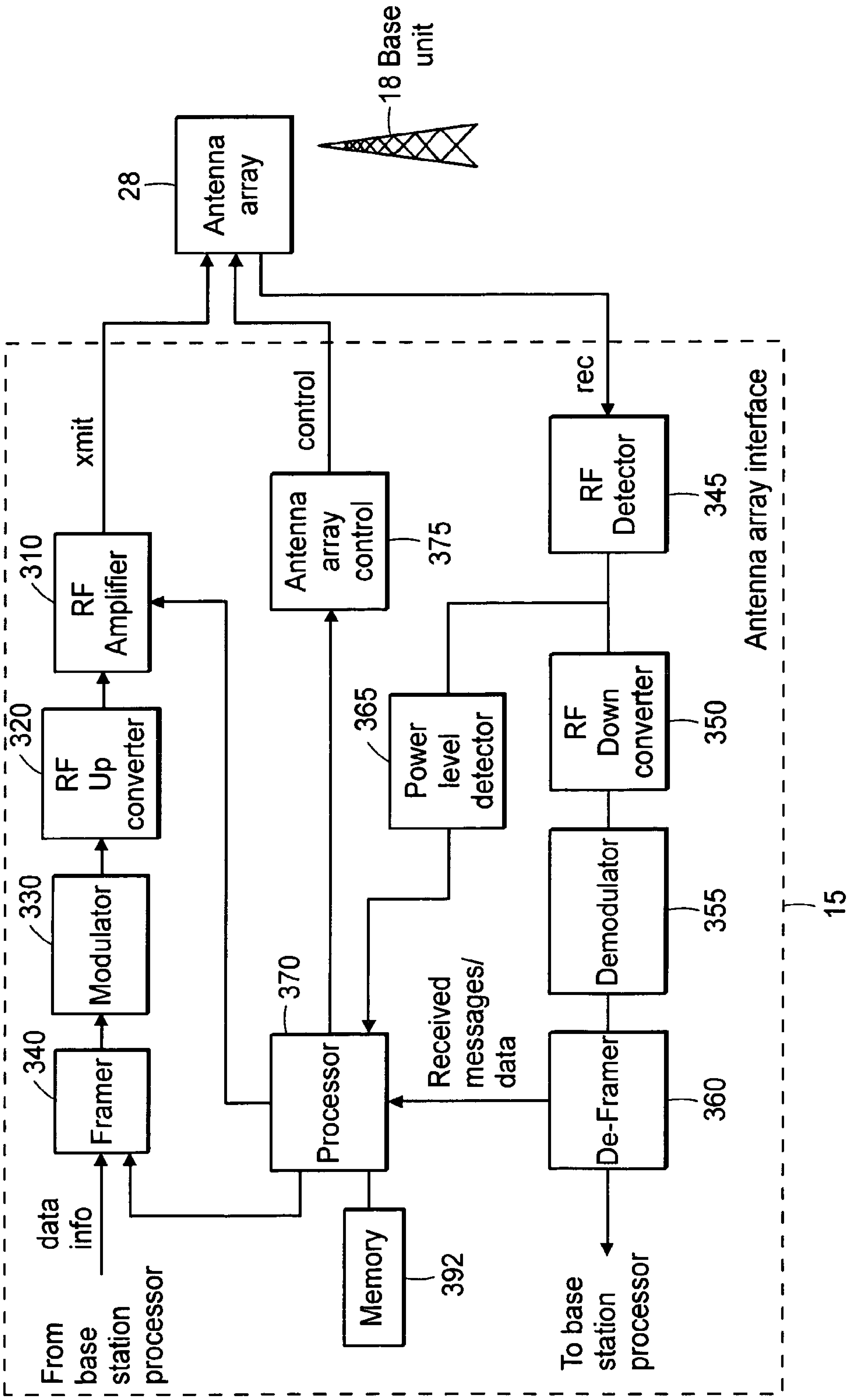

10
Server
30
24
Gateway
22
Base station processor
20
Antenna array interface
34
18
28
42-1, 42-2, ..., 42-n
paging
traffic
maint
41
43
40
FWD link
REV link
50
Access
Traffic
Maint
51
53
52-1, 52-2, ..., 52-m
Antenna array interface
16-1
15-1
Subscriber unit
14-1
12-1
16-2
15-2
14-2
12-2
16-h
15-h
14-h
12-h
16-m
15-m
14-m
12-m
26

FIG. 1



To subscriber
data info
Framer
240
Modulator
230
RF Up converter
220
RF Amplifier (adjustable)
210
xmit
Memory
292
Processor
270
Antenna array control
275
control
Received feedback information
Power level detector
265
To subscriber
De - framer
260
Demodulator
255
RF Down converter
250
RF Detector
245
rec
Antenna array interface
15
16
296

FIG. 2



18 Base unit
28
Antenna array
xmit
control
rec
310
RF Amplifier
320
RF Up converter
330
Modulator
340
Framer
Antenna array control
375
RF Detector
345
Power level detector
365
RF Down converter
350
Demodulator
355
De-Framer
360
370
Processor
Received messages/ data
Memory
392
data info
From base station processor
To base station processor
Antenna array interface
15

FIG. 3

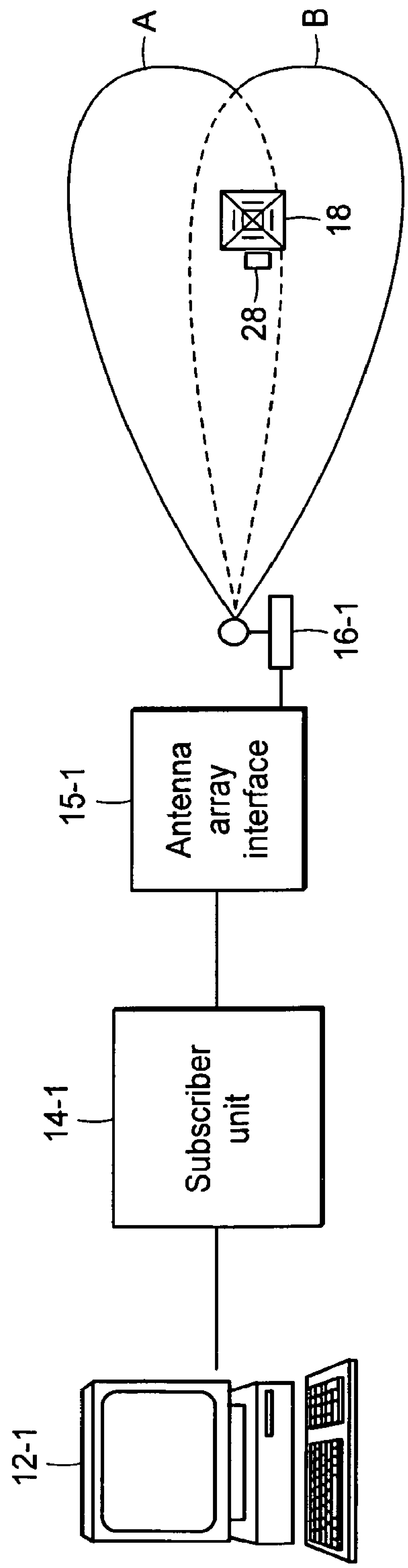

A
B
18
28
16-1
15-1
Antenna array interface
14-1
Subscriber unit
12-1

FIG. 4

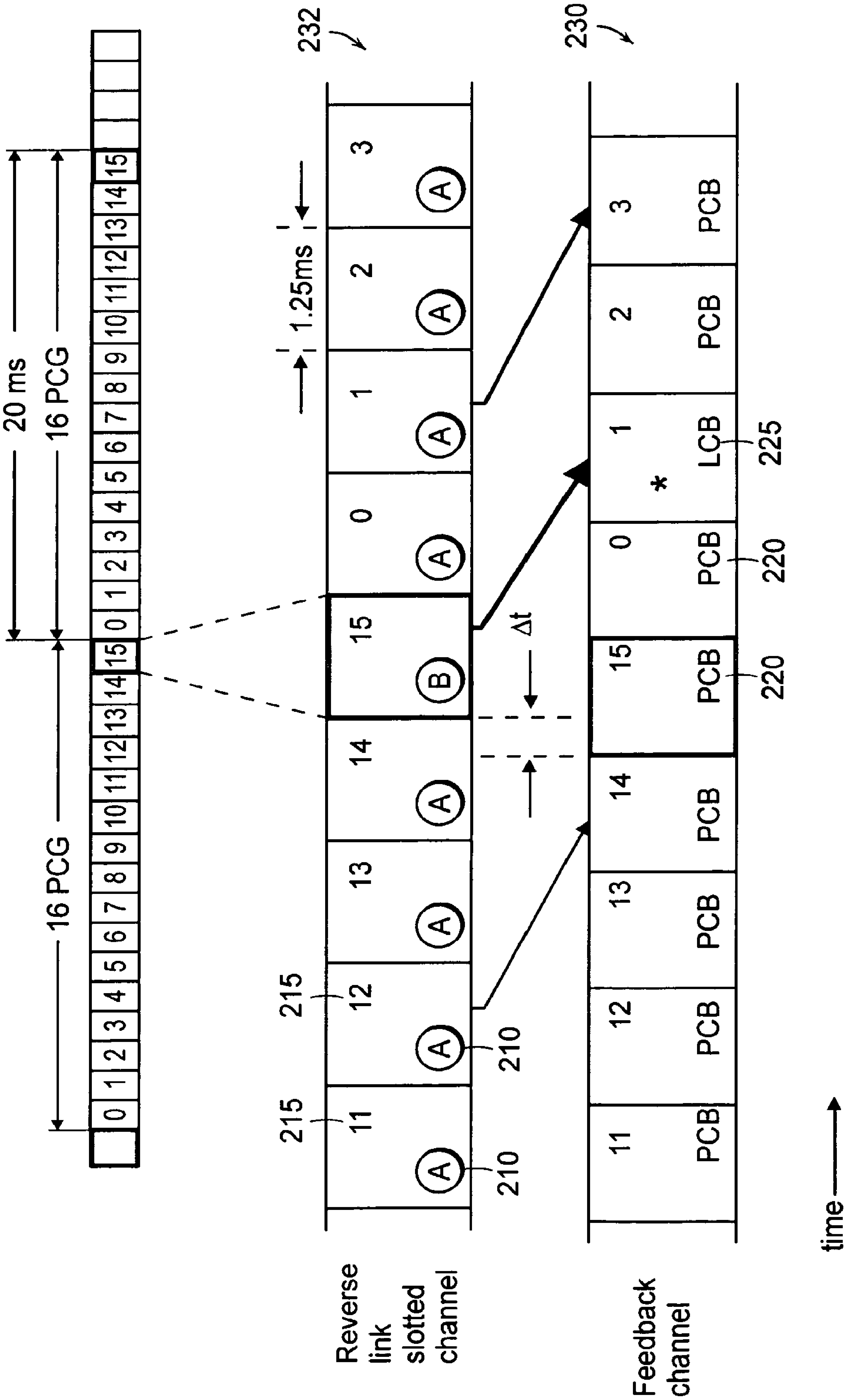

20 ms
16 PCG
16 PCG
1.25ms
Δt
232
230
215
210
220
225
PCB
LCB
Reverse link slotted channel
Feedback channel
time

FIG. 5

ANTENNA CONTROL SYSTEM AND METHOD

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 09/999,172 filed Nov. 30, 2001, which claims the benefit of U.S. Provisional Application Ser. No. 60/251,148 filed Dec. 4, 2000 and U.S. Provisional Application Ser. No. 60/250,908 filed Dec. 1, 2000, the contents of which are hereby incorporated by reference herein.

BACKGROUND

Precise power control in wireless communication systems such as cellular mobile telephone systems can be problematic, especially at the edge of a cell where interference is often the highest. Due to potential interference, the benefit of techniques such as high order modulation to transmit at higher data rates can be limited.

Code Division Multiple Access (CDMA) systems such as IS-95 and IS-2000 are interference limited, and their inherent capacity generally can be enhanced using beamsteering techniques. For example, based on indoor and outdoor field trials, significant improvements in signal to interference ratio (SIR) has been achieved using directional antenna arrays.

SUMMARY

One aspect of the present invention is directed toward a system and method to increase the bandwidth of a wireless communication system. In an illustrative embodiment, each of multiple directional transmissions from a transmitter of a subscriber unit is received at a receiver unit such as a base unit of a CDMA (Code Division Multiple Access) communication system. A quality of received signals at the receiver unit is then determined for each of the multiple directional transmissions from the transmitter. Based on the detected quality of received signals, the directional transmission from the transmitter that produces a higher quality received signal at the receiver can be identified. More optimal antenna settings of the transmitter can thus be determined by comparing link quality metrics generated for each of multiple directional transmissions. Consequently, settings of the subscriber unit transmitter can be adjusted to support more efficient directional transmissions to a base station receiver.

A link quality message indicating which of multiple directional transmissions from the transmitter produces a higher quality received signal can then be communicated to the subscriber unit. This feedback information can be conveyed in a number of ways. For example, a link quality message can be transmitted to the subscriber units over a dedicated, shared channel such as a feedback channel partitioned into periodically repeating sequences of frames. In a more specific application, feedback messages are communicated to a subscriber unit on a forward link CDMA channel via a technique such as bit-puncturing on an assigned forward link channel.

A link quality message can be a metric based on system parameters. For instance, the receiver unit or base unit can measure a power level of a received signal for each of multiple directional transmissions from the transmitter of a subscriber unit. Based on received power levels for each of multiple directional transmissions, a preferred antenna setting for the subscriber unit and corresponding transmitter can be determined. A link quality message can be based on other suitable system parameters such as a signal to noise ratio or bit error rate detected at the receiver unit.

In one application, a link quality message communicated to a subscriber unit is a single bit indicating which of two previous directional transmissions from the subscriber unit produces a higher quality received signal at the base unit. Typically, a subscriber unit is synchronized with the base station for transmitting a majority of data information to the base unit based on first directional antenna settings and occasionally transmitting from the subscriber unit to the base unit based on second directional antenna settings.

A transmit lobe of the subscriber unit and corresponding wireless transmitter can be multiplexed between two or more different angular positions in a horizontal plane. In this way, the subscriber unit can transmit along two or more paths, each having a potentially different path loss depending on environmental conditions.

If it is determined that new antenna settings of a subscriber unit would be more optimal in lieu of previously used settings, the transmitter or antenna array of the subscriber unit can be adjusted accordingly. Consequently, a beam-steering subscriber unit that is mobile with respect to a base unit can be adjusted so that a wireless communication link is continually optimized for use. The receiver can use beam-steering techniques to receive a wireless signal.

Link quality messages can be transmitted to corresponding subscriber units over a dedicated or shared channel. In this instance, a forward link channel from the base unit can be partitioned to transmit multiple feedback messages to each of multiple subscriber units on a forward link CDMA channel.

Each subscriber unit is optionally assigned use of particular time slots or data fields of the feedback channel to retrieve feedback messages. Part of a time-slot can be allocated for use by a subscriber unit to receive feedback messages indicating how to adjust its antenna settings.

Based on these techniques, a base unit can monitor received signals and generate feedback information to maintain efficient wireless links with each of multiple subscriber units.

Another aspect of the present invention involves providing feedback information to one or multiple subscriber units so that their corresponding transmit settings such as power output levels are minimized for a particular antenna orientation and position in a shared wireless communication system. For instance, a subscriber unit can transmit Power Control Groups (PCGs) to the base unit over multiple successive time slots or frames. In this instance, the PCGs can be analyzed at the base unit for generating feedback information that is communicated to the subscriber unit.

A feedback channel from the base unit to the subscriber unit can be used to adjust power settings of a transmitter at the subscriber unit so that its data transmissions are optimized. For example, a continuous, periodic or intermittent bit stream can be transmitted on a feedback channel to the subscriber unit indicating whether it should increase or decrease its power output level for future transmissions along a particular path.

Generally, multiple types of antenna or transmitter settings can be adjusted based on receiving two or more types of feedback messages in a feedback channel. Consequently, two or more feedback control loops can be supported to adjust directional transmissions of the transmitter.

A single feedback bit such as a power control bit received in the feedback channel can indicate whether power output at the subscriber unit should be increased or decreased for future transmissions. Thus, for each of multiple framed transmissions from the subscriber unit, a power level can be increased or decreased, for example, by 1 dB. The power control bit can be dithered between logic high and logic low levels for successive transmissions over the feedback channel so that the subscriber unit transmits at an optimal or near-optimal power output level.

In one application, the power control bit is occasionally substituted with a lobe compare bit to control a directional output of the transmitter rather than power output. Accordingly, information transmitted in a data field, time slot or frame of the feedback channel can be used to control multiple aspects of a subscriber unit.

In certain situations, the transmitter settings will be adjusted to transmit along a new direction. Since a path loss can be different for the new directional transmissions, the power control feedback messages can then be communicated to readjust a power output of the transmitter.

A specific subscriber unit can identify a type of feedback control message based on a time slot or frame in which it is transmitted. For example, a position of a feedback message in a frame of multiple repeating sequences of frames can be used to identify a type of feedback message received over the feedback channel. No additional data such as a tag indicating the type of feedback message is necessary. However, it should be noted that in one application, a tag or message type identifier is used to indicate the type of feedback message rather than the position of a frame in a sequence of frames to identify a message type. Consequently, a power control loop and lobe control loop can be established between a subscriber unit and base unit to optimize transmitter settings at the subscriber unit.

As discussed, the subscriber unit can occasionally transmit along a different direction in a specified time interval, time slot or frame. The base unit can be synchronized to receive the signal along the different direction and, instead of communicating a power control bit back to the subscriber unit in a specified feedback time slot, the base station can transmit a lobe compare bit in a feedback channel to the subscriber unit. The lobe compare bit can indicate which transmitter setting at the subscriber unit is perceived to be better for directional data transmissions.

A bit or bit sequence in a time slot of a feedback channel can have a unique purpose depending on which time slot or data field it is transmitted. In one application, feedback is provided to control two aspects of a transmitter. First, messages in the feedback channel can be used to provide feedback information to control transmitter power output settings for directional transmissions from a subscriber unit to the base unit. Second, a bit or sequence of bits in the feedback channel can be used to identify which of multiple directional settings of the subscriber unit is optimal for the wireless communication system. Consequently, a two-tiered control loop including multiple types of feedback messages can be used to maintain antenna settings.

BRIEF DESCRIPTION OF THE DRAWINGS

A more detailed understanding may be had from the following description, given by way of example in conjunction with the accompanying drawings wherein:

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

FIG. **1** is a block diagram of a wireless communication system according to certain principles of the present invention.

FIG. **2** is a block diagram of a transceiver interface at a subscriber unit according to certain principles of the present invention.

FIG. **3** is a block diagram of a transceiver interface at a base station according to certain principles of the present invention.

FIG. **4** is a diagram illustrating different radiation lobe patterns generated by an antenna device according to certain principles of the present invention.

FIG. **5** is a timing diagram illustrating a time-slotted forward and reverse link channel supporting feedback according to certain principals of the present invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

FIG. **1** is a block diagram illustrating a communication system supporting the transmission of data information over multiple allocated wireless communication channels according to certain principles of the present invention. Users at remote terminals such as personal computer device **12** can compete for wireless bandwidth allocation. Hence, it is desirable that limited resources in wireless communication system **10** are optimized for data throughput.

According to the following description, communication system **10** is described as a wireless communication link such as a wireless CDMA (Code Division Multiple Access) or other spread spectrum system in which radio channels are shared among multiple users. However, it should be noted that the techniques described herein can be applied in any suitable application supporting shared access. For example, the principles of the present invention can be applied to other types of media such as cellular telephone connections, wireless Local Area Network (LAN) connections, line of sight connections, or other physical media to which allocation of wireless resources such as data channels are granted on an as-needed basis.

As shown, communication system **10** can include a number of Personal Computer (PC) devices **12-1**, **12-2**, . . . **12**-*h*, . . . **12**-*m*, corresponding Subscriber Access Units (SAUs) or terminals **14-1**, **14-2**, . . . **14**-*h*, . . . **14**-*m*, and associated directional antenna arrays **16-1**, **16-2**, . . . **16**-*h*, . . . **16**-*m*. Centrally located equipment can include base station antenna array **28**, and corresponding base station processor (BSP) **20** and antenna array interface **34**. The use of specific types of equipment can vary depending on an application. For example, base station antenna array **28** and subscriber unit antenna array **16** can include antenna devices, transmitter, receivers, transceivers, dipole antennas, and transducers that transmit or receive wireless signals.

Generally, base station processor **20** can provide connections to and from a network gateway **22**, network **24** such as the Internet, and network file server **30**. Connectivity can include additional wireless links to support multiple logical connections.

In one application, communication system **10** is a demand access, point to multi-point wireless communication system such that PC devices **12** can transmit data to and receive data from network server **30** through bi-directional wireless, logical connections implemented over forward links **40** and reverse links **50**. That is, in the point to multi-point multiple access wireless communication system **10** as shown, a given base station processor **20** can support communication with a number of different subscriber units **14** in a manner which is similar to a cellular telephone or mobile communication network. Accordingly, system **10** can provide a framework for a CDMA wireless communication system in which digital information is relayed on-demand between multiple mobile cellular users and a hardwired network **24** such as the Internet.

PC devices **12** are typically laptop computers, handheld units, Internet-enabled cellular telephones, Personal Digital Assistant (PDA)-type computers, digital processors or other end user devices, although any suitable type of processing device can be used in place of PC devices **12**.

It should be noted that PC devices **12** need not be terminal devices. For example, a subscriber or access unit **14**-*m* can be connected to network **26** such as LAN (Local Area Network).

Typically, each PC device **12** is connected to a respective subscriber unit **14** through a suitable wired connection such as an Ethernet-type connection or similar cable.

Each subscriber unit **14** can permit its associated PC device **12** access to network file server **30** or other target devices on network **24**. In a reverse link **50** direction, that is, for data traffic traveling from PC device **12** towards server **30**, PC device **12** transmits based on a transport protocol such as an Internet Protocol (IP) level packet to the subscriber unit **14**. One aspect of the transport layer or transport protocol is to ensure quality of service and accurate delivery of information between logical computer-to-computer connections. In the OSI (Organization for Standardization's Open Systems Interconnection) model, the transport layer is one level above the network layer and is the fourth of seven layers.

In addition to the use of a transport protocol to support computer-to-computer communications, subscriber unit **14** then encapsulates the wired framing information (i.e., Ethernet framing) with appropriate wireless connection framing that is used to frame information for transmissions over wireless reverse link **50**. In other words, data packets are split, combined, or rebundled for transmission over the wireless link.

After the information is framed, the appropriately formatted wireless data packets then travel over one of the radio channels that comprise reverse link **50** through antennas **16** and **28**. At the central base station location, base station processor **20** and antenna array interface then extract the radio link framed data packets and reformats the packets into an original or near original IP format. The packets can then be subsequently routed through gateway **22** and any number or type of networks **24** to an ultimate destination such as a network file server **30**. Accordingly, network data messages can be packed for transmission over a wireless link and unpacked for transmission over a wired or optical network.

In one application, information generated by PC devices **12** are based on a TCP/IP protocol. Consequently, PC devices **12** can have access to digital information such as web pages available on the Internet.

It should be noted that other types of digital information can be transmitted over radio channels or sub-channels of communication system **10** based on the principles of the present invention. More specifically, the data information can be any type of data information encapsulated using a suitable network protocol.

Data can also be transmitted from network file server **30** to PCs **12** on forward link **40**. In this instance, network data such as an Internet Protocol (IP) packets originating at file server **30** travel on network **24** through gateway **22** to eventually arrive at base station processor **20**. In a similar manner as discussed, appropriate wireless protocol framing can then be added to raw data such as IP packets for communication of the packets over a wireless forward link **40**. Modulation and up-converter circuits can be employed to produce a signal suitable for radio transmission on one or more forward link traffic channels **42**.

The newly framed packets travel through base unit **18** and antenna array **16** to the intended receiver subscriber unit **14**. An appropriate target subscriber unit **14** demodulates and decodes the radio signal or signals to receive the wireless packet formatting layer, and forwards the packet or data packets to the intended PC device **12** that performs IP layer processing. It should be noted that subscriber unit **14**-*m* can be coupled to another network such as network **26** as shown.

A given PC device **12** and file server **30** can therefore be viewed as the end points of a duplex connection at the IP level.

Once a connection is established between base station processor **20** and a corresponding subscriber unit **14**, a user at PC device **12** can transmit data to and receive data from file server **30** on an as-needed basis. More specifically, one or multiple channels can be allocated to each of multiple users on an as-needed basis to transmit at higher data rates.

Reverse link **50** optionally includes different types of logical and/or physical radio channels such as access channel **51**, multiple traffic channels **52-1**, . . . **52**-*m,* and maintenance channel **53**.

A combination of these channels can be used to maintain one or multiple wireless links. Reverse link access channel **51** can be used by the subscriber units **14** to send messages to base station processor **20** and request that traffic channels be granted to them. For example, traffic channels carrying data packets can be assigned or reallocated to one or multiple users on an as-needed basis. Assigned traffic channels **52** then carry payload data from subscriber unit **14** to base station processor **20**. Notably, a given connection can have more than one traffic channel **52** assigned to it.

Maintenance channel **53** can also carry information such as synchronization and power control messages to further support transmission of information over both the reverse link **50** and forward link **40**.

In a similar manner, the forward link **40** can include a paging channel **41**, which is used by base station processor **20** to inform a subscriber unit **14** of general information such as that one or multiple forward link traffic channels **52** have been allocated or assigned to it for the transmission of data. Additionally, the channel can be used to inform subscriber units **14** of allocated or assigned traffic channels **52** in the reverse link direction.

Traffic channels **42-1** . . . **42**-*n* on forward link **40** can be used to carry payload information from base station processor **20** to subscriber units **14**. Additionally, maintenance channels can carry synchronization and power control information on forward link **40** from base station processor **20** to subscriber units **14**.

Traffic channels **42** on forward link **40** can be shared based on a Time Division Multiplexing scheme among multiple subscriber units **14**. Specifically, a forward link traffic channel **42** can be partitioned into a predetermined number of periodically repeating time slots for transmission of data packets to multiple subscriber units **14**.

It should be noted that a given subscriber unit **14** can have, at any instant in time, multiple time slots or no time slots of a wireless channel assigned to it for use. However, in certain applications, an entire time-slotted forward or reverse link traffic channel can be assigned for use by a particular subscriber unit **16**. Consequently, multiple subscriber units **14** sharing wireless resources can transmit short bursts of sporadically generated data at high throughput rates.

Base station **18** includes antenna array **28** that can be used in conjunction with antenna array interface **34** for detecting the received signal quality level of reverse link directional transmissions from corresponding antenna arrays **16** coupled to subscriber units **14**.

Antenna array **16** coupled to corresponding subscriber units **14** can be steerable so that a radiation pattern from a subscriber unit **14** can be directed towards a particular target such as base unit **18** and, more specifically antenna array **28**.

Additionally, directional transmissions from antenna array **16** can vary depending on a time slot of a channel in which it is transmitted. That is, a transmitter can transmit a wireless signal in a first direction for one time slot and transmit in a second direction for another time slot.

Implementations of directional antenna systems are described in co-pending U.S. patent application entitled "A Method of Use for an Adaptive Antenna in Same Frequency Networks" Ser. No. 09/579,084 filed on May 25, 2000, and U.S. patent application entitled "Adaptive Antenna for Use in Wireless Communication Systems" Ser. No. 09/859,001 filed on May 16, 2001 the entire teachings of which are incorporated herein by this reference. Generally, any directional antenna array or transducer device can be advantageously employed to transmit and receive wireless signals according to certain principles of the present invention.

Since multiple users can be assigned CDMA channels on the same frequency, typically there is interference among users competing for available wireless bandwidth. For example, two different subscriber units **16** can transmit information over a reverse link channel to base unit **18** from the same general direction. Thus, a signal from a subscriber unit **14** can appear as noise to another subscriber unit **14** when such channels are generated onto the same carrier frequency, but using different coded channels.

Certain aspects of antenna array **16** can be controlled to reduce interference between adjacently transmitting subscriber units **14** to increase the overall bandwidth of wireless communication system **10**. For example, the shape of the radiation pattern of antenna array **16** and its power output level can be optimized for a particular application. More specifically, directional transmissions from antenna array **16** can be adjusted so that the output beam or lobe is wider or narrower.

Additionally, the power output level at which the data is transmitted on reverse link **50** from antenna array **16** can be controlled so that a corresponding wireless signal in the reverse link can be detected by base unit **18**, but not at such a high power transmit level that it causes unnecessary interference with other users. Typically, there is an optimal signal-to-noise ratio for a given reverse link channel that results in maximum throughput of communication system **10** and reduction of overall power consumption by subscriber unit **14**. Reduced power consumption can be particularly important in applications where subscriber units **14** and related equipment such as computer devices **12** are powered by a finite power source such as a battery. Generally, aspects of the present invention can be employed so that a power source lasts longer.

FIG. **2** is a block diagram of an antenna array and corresponding interface to transmit and receive a wireless signal from a subscriber unit according to certain principles of the present invention.

As shown, antenna array **16** is controlled by array controller **275** to steer a transmit or receive beam. Consequently, antenna array **16** can steer the directionality and coverage area of output beam **296**.

Antenna array **16** can be coupled to antenna array interface **15** via a cable or it is optionally integrated with interface **15** as a single unit. Likewise a corresponding subscriber unit **14** can be connected to antenna array interface **15** via a cable or the combination of subscriber unit **14** and interface **15** optionally integrated as a single unit.

The power level of output beam **296** can be controlled by adjusting RF amplifier **210**. Generally, processor **270** generates control signals to adjust RF amplifier **210** and corresponding output beam **296**.

In a transmit mode, data information from subscriber unit **14** is fed into framer **240** where it is framed with a protocol for transmission over a wireless link as discussed. The framed data is in turn is fed to modulator **230** for modulation of data onto a carrier frequency. Modulation can be any suitable type such as BPSK (Binary Phase Shift Keying), QPSK (Quadrature Phase Shift Keying), 8-psk, up to n-psk.

Modulated signals generated by modulator **230** are then fed to RF converter **220** that, in combination with RF amplifier **210**, drive antenna array **16**. RF amplifier **210** is adjustable so that a power level of output beam **296** can be controlled based on input from processor **270**.

Antenna array interface **15** can be adjusted for receiving wireless data information from base unit **18**. RF detector **245** detects the presence of a received RF signal. Power level detector **265** can be used to detect a power level of the received signal. Output information generated by power level detector **265** can be analyzed by processor **270**.

As depicted in the block diagram, RF down converter **250** converts the received signal and feeds the signal to demodulator **255**. The signal is then demodulated and decoded by de-framer **260** to retrieve packaged data information that is eventually reformatted and forwarded to subscriber unit **14**.

More details of wireless transmitter and receiver circuits can be found in U.S. application Ser. No. 09/775,304 entitled "Alternate Channel for Carrying Selected Message Types" filed on Feb. 1, 2001, the teachings of which are incorporated herein by reference.

FIG. **3** is a block diagram of an antenna array and corresponding interface to transmit and receive wireless signals from a base unit according to certain principles of the present invention.

As shown, antenna array interface **34** can include similar circuitry and functionality as that described in FIG. **2** for transmitting and receiving wireless signals. More details regarding how base unit **18** communicates with subscriber unit **14** will be described later in this specification.

FIG. **4** is a top view diagram of exemplary radiation patterns produced by a corresponding directional antenna array according to certain principles of the present invention. As shown, subscriber unit **14-1** and antenna array interface **15-1** control a receive or transmit radiation pattern of antenna array **16-1** directed towards base unit **18**. In this instance, both lobes A and B can be used to transmit information to base unit **18**, although base unit **18** is near the edge of lobe A and, therefore, is almost out of receiving range. If antenna array **16-1** happened to rotate an appreciable amount in a counter clockwise direction from the top view as shown, lobe A would no longer be received at base unit **18**. In this latter instance, a transmit lobe may not be detectable at base unit **18** due to its directionality or low power transmit level at a particular point on the lobe.

As previously discussed, one aspect of the radiation output pattern **296** of transmitter or antenna array **16** involves controlling a direction of a lobe while another aspect involves controlling its power output level. Lobe A illustrates that antenna array **16** needlessly transmits extra power to base unit **18**, potentially causing unnecessary interference to other subscriber units **14-2**, . . . **14**-*m*. Interference can be exacerbated when a subscriber unit **14** is at the edge of a cell. Generally, base station **18** can receive corresponding reverse link **50** data transmissions from antenna array **16-1** at the side of lobe A. Comparatively, lobe B is approximately centered so that base unit **18** can receive the reverse link signal even if the power output level of lobe B were reduced.

Although antenna array **16-1** can be controlled to transmit a wireless signal in different directions such as that shown by lobe A and lobe B, antenna array **16-1** can be designed to transmit along any vertical direction as well as horizontal direction. In one application, antenna array **16-1** transmits a directional beam using beam-steering techniques. Accordingly, communication system **10** can support more efficient communication between subscriber units **14** and base station **18** no matter their position in **3**-dimensional space.

FIG. **5** is a diagram illustrating message frame information for reverse and forward link channels according to certain principles of the present invention. As shown, forward link frames are offset in time by round-trip delay Δt. Generally, a signal is transmitted from antenna array **16** to antenna array **28** or generally base unit **18** in a time frame **215** of reverse link channel **232**. A quality of received signal can be analyzed at base unit **18** to provide feedback information to transmitting antenna array **16**. For example, feedback messages can be transmitted in the opposite direction on forward link **40** and, more specifically, feedback channel **230** to one or multiple subscriber units **14**.

According to one aspect of the present invention as mentioned, an optimal directional transmission from a subscriber unit **14** and corresponding antenna array **16** can be determined so that data information can be efficiently transmitted on the reverse link **50** without causing undue noise interference to other subscribers **14-2** . . . **14-*m*** or yet other subscriber units in different cells. This technique of optimizing the use of particular antenna arrays **16** of corresponding subscriber units **14** can include adjusting both the power level and directionality of a corresponding output from an antenna array **16**.

Notably, a path loss between base unit **18** and subscriber unit **14** can vary depending on directionality of antenna array **16**. Thus, shifting a direction of a transmitting lobe of a single antenna array **16** for future directional transmissions can result in a power savings since the power transmission level of other subscriber units **14** can then be reduced as a result of reduced interference. The power transmission level of reverse links can also be increased if a signal is not detected. Consequently, communication system **10** can support more robust communications between one or multiple base stations and multiple subscriber units **14**.

As previously mentioned, another aspect of the present invention involves adjusting a power level of the signals transmitted by antenna array **16**. Reverse link slotted channel **232** of an exemplary reverse link channel **50** can include periodically repeating time slotted messages in which information is transmitted on reverse link **50** to base unit **18** and, more specifically, to antenna array **28**.

As previously discussed, the information transmitted from a subscriber unit **14** can be rebundled network messages. As shown, time-slots or sequence of frames **0-15** can periodically repeat every 20 ms. Each of the 16 frames or 16 PCGs (Power Control Groups) is preferably 1.25 mS (milliseconds) in duration. This can vary depending on the application.

Generally, reverse link slotted channel **232** can be any suitable, partitioned reverse link channel **50** such as those previously discussed. Similarly, feedback channel **230** can be a shared or dedicated channel for transmitting feedback messages from base unit **18** to one or multiple subscriber units **14**.

As its name suggests, frame reference numeral **215** indicates the number of a time slot in a given cycle of 16 PCGs as shown. Circled letter **210** indicates the lobe over which information is transmitted in that particular time frame from subscriber unit **14-1** over antenna array **16-1** to base unit **18** as shown in FIG. **2**. For example, antenna array **16-1** can transmit information over a reverse link channel to base unit **18** using lobe A for each of frames **0-14**. Antenna device **16-1** can then alter its directional transmissions to transmit information over the reverse link channel using lobe B during frame **15**. In this way, subscriber unit **14-1** multiplexes its directional transmissions to base unit **18** using different directional lobe patterns.

It should be noted that this method of multiplexing can be expanded so that antenna array **16** multiplexes its data transmissions along any number of lobes or directions. In other words, a subscriber unit **14** can utilize a scanning technique to identify which of multiple directional transmissions are optimal.

Since base unit **18** and subscriber unit **16-1** are synchronized with respect to each other for receiving transmitted data in either the reverse or forward link direction, power level detector **365** at base unit **18** can be used to measure a power level of a received signal at antenna array **28** for a given time frame as transmitted by antenna device **16-1**. Subsequently, a message can be transmitted from antenna array **28** to subscriber unit **14-1** regarding the power level measurement. In this way, feedback information can be provided by base unit **18** to a corresponding subscriber unit **14**.

It should be noted that occasional, newly directed data transmissions from multiple subscriber units **14** can be offset in time from each other so that communication system **10** does not experience a sudden change in interference levels that may otherwise result if multiple subscriber units **14** simultaneously transmit in new directions at the same time.

Referring again to FIGS. **2-5** subscriber unit **14** generates a wireless signal to base unit **18** in reverse link slotted channel **232**. Processor **270** of antenna array interface **15** drives array controller **275** to adjust the antenna array settings for each frame or time slot. For example, array controller **275** adjusts the settings of antenna array **16** so that it transmits output beam Lobe A for time slots **0-14** and output beam Lobe B for time slot **15**.

In this instance, the output signal transmitted by antenna array **16** is received at base unit antenna array **28**. The received signal is processed and decoded as previously discussed. A quality of received signal during each time frame can be determined by detecting a power level of the received signal via power level detector **365**.

As previously discussed, the quality of received signal also can be quantified based on a bit error rate or signal-to-noise ratio. Based on the quality of received signal, processor **370** generates a feedback message that is transmitted to subscriber unit **14** over feedback channel **230**.

One type of feedback message is a power control message. For example, a Power Control Bit (PCB) **220** is transmitted from base unit **18**. Generally, subscriber unit **14** transmits over Lobe A to base unit **18**, which then detects a quality of received signal as discussed. Processor **370** in base unit **18** then compares the detected link quality of received signal to a threshold. If the quality of received signal is below the threshold, a PCB **220** such as a logic '1' is transmitted from the base unit in feedback channel **230** to indicate that subscriber unit **14** should increase its power output level for successive transmissions. Conversely, if a quality or power level of a received signal is higher than the threshold, processor **370** can generate a PCB **220** feedback message at a logic '0' indicating that subscriber unit **14** should decrease its power output level for successive transmissions. Thresholds are chosen so that use of resources in communication system **10** are optimized for multiple users.

In this way, the power transmission level can be controlled via the feedback information transmitted to the base unit **18** over the forward link channel. More specifically, successive packets of Power Control Bit (PCB) **220** information can be transmitted to a corresponding subscriber unit **14** to indicate whether to increase or decrease its power transmission level. Thus, a power level output of antenna array **16** can be adjusted to account for changes in the immediate environment and path loss. For example, a new subscriber may begin transmitting information in the immediate vicinity, increasing the noise level in the area. In this instance, subscriber unit **14** may need to increase its power output level to maintain a wireless link with base unit **18**. In other situations, a path loss for a particular lobe may change depending on weather conditions or movement of a subscriber unit **14**.

Power Control Bit (PCB) **220** can indicate that the subscriber unit **14-1** should increase or decrease its power output level by a specified amount such as one dB, depending on the state of the bit. For example, a logic "1" can indicate to increase the power output level of antenna array **16-1** while a logic "0" can indicate to decrease its power output level. In this way, the power output level of antenna array **16-1** can be optimized so that it does not needlessly transmit at excessive levels, which could appear as interfering noise to other channels.

It should be noted that power control bit **220** as transmitted in a forward link channel to a corresponding subscriber unit **14** is typically delayed since it can take time to process the received reverse link signal at base unit **18** and make a determination whether the corresponding subscriber unit **14-1** should increase or decrease its power level output. As shown in FIG. **5**, power control bit **220** in frame **14** of feedback channel **230** as transmitted by base unit **18** is a feedback message based on a previous power measurement of the reverse link slotted channel **232** transmitted from a subscriber unit **14** during frame **12**. The amount of such a delay can vary depending on the application.

A particular metric reflecting the power output level of transmitting antenna array **16-1** can be based on one or multiple parameters. For example, the metric can be based on a link quality measurement such as bit error rate or signal-to-noise ratio of a selected reverse link channel, or both. Generally, any suitable metric reflecting link quality can be used to generate feedback information to subscriber unit **14**.

Antenna array **16-1** can multiplex transmissions in different directions such as along lobe A and lobe B to transmit during a reverse link frame. As shown, subscriber unit **14-1** transmits information in the selected reverse link channel through lobe B in frame **15** of the reverse link channel. Prior to transmission of data along lobe B during frame **15**, data from subscriber unit **14-1** on the reverse link channel can be transmitted along lobe A for each of multiple frames **0-14**. This 15:1 multiplexing ratio is merely exemplary and can modified depending on the application.

Feedback information transmitted on feedback channel **230** is received at subscriber unit **14** and, specifically, antenna array **16**. The message is processed by processor **270** that, in turn, uses the feedback message to adjust aspects of antenna array **16**. For example, based on feedback messages, processor **270** can generate control commands to adjust RF amplifier **210** and the power output level of subscriber unit **14**.

Typically, the power output for data transmissions using lobe A and lobe B are equal or within 1 dB of each other. Similar to previous reverse link transmissions for frames **0-14**, the power level or other suitable link quality metric of the received reverse link signal for the duration of frame **15** is measured at base unit **18**. More specifically, signals transmitted by subscriber unit **14** in time slots of the reverse link slotted channel **232** can be received at base unit **18**. As discussed the link quality of the received signal at base unit **18** can be detected by power level detector **365** or determined by a bit error rate of received signal data. Based on calculated link quality and a comparison of the received signal for previous lobe transmissions, processor **370** can generate feedback information that is transmitted to the subscriber unit **14** indicating which previous directional transmission from subscriber unit **14** produces a high quality received signal. In one application, an actual link quality metric calculated at base station **18** is communicated to subscriber unit **14** over a wireless channel.

Instead of processing a power measurement to generate a power control bit **220** and transmitting the power control bit **220** to a subscriber unit **14-1** in the feedback channel **230**, base unit **18** can analyze a received signal for a new directional transmission and generate a lobe compare bit (LCB) **225** that is transmitted in forward link slot #**1**. As discussed for PCB bit **220**, LCB bit **225** in forward link frame **1** is delayed so that base unit **18** can process information received in reverse link frame **15**.

A position of the frame in a sequence of periodically repeating frames can be used to identify the type of feedback message received.

Lobe compare bit **225** can provide a relative indication of the received power level or link quality on the reverse link channel **232** for multiple directional transmissions such as successive frames **14** and **15**. For example, base unit **18** and, more specifically, antenna array interface **15** can separately measure a received link quality of reverse link channel **232** for frame **14** and, thereafter, frame **15**. These link quality measurements for different lobe transmissions can be compared to each other by processor **370** to generate the lobe compare bit (LCB) **225**. Thus, LCB bit **225** can be used to indicate which of the lobes, A or B, provides a stronger signal or better link quality. A logic "1" transmitted in feedback channel **230** can indicate that lobe B has a greater received power level than lobe A, while a logic "0" can indicate that lobe B has a lower received power level than lobe A. Thus, a corresponding subscriber unit **14** can be notified via feedback messages in the forward link channel which of multiple directional transmission of antenna device **16-1** is optimal for use. A subscriber unit **14** can then adjust its directional transmissions based on the LCB bit **225**. More specifically, received feedback information can be used by processor **270** to generate commands that are in turn used by array controller **275** to adjust directional output beam **296** from antenna array **16**.

Subscriber unit **14** or base station **18** can determine in which direction the occasional new lobe will be directed based on past experience and information stored in memory. Base unit **18** can send a message to base unit **18** indicating an experimental directional lobe or general antenna settings that are to be used for future directional transmissions.

As discussed, lobe compare bit **225** can be transmitted to a subscriber unit **16-1** in lieu of the power control bit **220** as transmitted in previous frames. Based on this method of providing dual-mode feedback, subscriber unit **14-1** can be notified which directional transmissions on antenna array **16-1** are optimal and, in addition, how the power output level of the antenna device **16-1** should be adjusted to maintain a link between the subscriber unit **14-1** and base unit **18**. Future directional transmissions from antenna array **16-1** therefore can be based on lobe B when it is a more optimal path. Accordingly, when lobe B becomes the main transmission direction, its power level can be reduced via the power control bit **220** as previously discussed so that its output is optimized for system **10**.

It should be noted that functionality provided by antenna array interface **15** can be duplicated in base unit **18** so that corresponding directional transmissions from the base unit **18** can be adjusted and monitored in a similar, but reverse manner as that previously discussed.

Directional transmissions based on multiplexing between lobes can be performed to sample potentially better wireless transmission paths to base unit **18**. For example, alternate paths from subscriber unit **14-1** to base unit **18** can be tested periodically or intermittently whether they have a lower path loss and would otherwise support data transmissions at lower power levels.

In certain applications, power control bit **220** and lobe compare bit **225** information are transmitted to subscriber unit **14-1** via bit-puncturing on a corresponding assigned forward link traffic channel. Alternatively, each subscriber unit **14** can be assigned a time-slot or a data field of repeating time slots of a dedicated forward link CDMA channel to receive the power control bit **220** and lobe compare bit **225**. Feedback messages are optimally tagged to identify their type.

According to other aspects of the present invention, multiple additional lobe positions can be compared with a base lobe setting, such as lobe A, to determine which of multiple possible directional antenna settings is optimal for subscriber unit **14-1** and communication system **10**. For example, subscriber unit **14-1** can be set to transmit data on baseline lobe A from subscriber unit **14-1** to base unit **18**. A received power level for lobe A and lobe B data transmissions can be compared as previously mentioned to determine which path or lobe provides a more optimal link between subscriber unit **14-1** and base unit **18**. Other lobe settings such as lobe B, lobe C, lobe D and so on can be compared to baseline setting of lobe A to determine which if any of the new possible lobe settings can be used to transmit data more efficiently to base unit **18**. It is anticipated, at least at times, that the power transmit level of a particular subscriber unit **14** can be reduced based on a new directional antenna setting. Accordingly, a new antenna setting can account for a changing position of a user or antenna array with respect to base unit **18** so that a wireless link is constantly maintained.

In a manner as previously mentioned, the additional power level compare information for multiple possible antenna or lobe settings can be transmitted to subscriber unit **14-1**. Lobe compare bits **225** for multiple possible new antenna settings can be used by subscriber unit **14** to determine an optimal antenna setting on which information shall be transmitted to base unit **18**.

Based on a comparison of multiple potential antenna settings with the baseline settings such as lobe A, subscriber unit **14-1** can optionally transmit information in a new direction or at a new power output level. Accordingly, a more precise determination as to which of the multiple lobe settings is optimal can be made prior to transmitting information on a new lobe setting. More specifically, multiple possible antenna settings can be considered before actually transmitting information based on a new setting. Two lobe settings such as lobe B and lobe C can be compared in multiple **20** mS cycles to determine which of the two antenna settings shall eventually be used to transmit data to base unit **18**.

It should be noted that subscriber unit **14-1** can monitor multiple lobe compare bits **225** for two or more potential lobe settings before changing from one lobe setting to another. This ensures that the lobe settings are not changed unnecessarily. Consider a situation where a baseline lobe setting is unusually noisy for a short period of time. For instance, a lobe compare bit may erroneously indicate that one lobe setting is better than another due to sporadic noise on a particular frequency channel even though such a channel otherwise generally provides a good link between subscriber unit **14-1** and base unit **18**. In this instance, it may not be desirable to switch to a new lobe setting until it is reasonably certain that the new lobe setting can sustain continued communications between the subscriber unit **14-1** and base unit **18** and that the new lobe setting is more optimal for future communications. A new lobe setting may unnecessarily interfere with another user.

When transmissions from a subscriber unit **14-1** in the reverse link will be switched to a new lobe setting, a message can be sent from the subscriber unit **14-1** to base unit **18** indicating these and other new antenna settings. In this way, base unit **18** can be apprised of the different lobe settings upon which information is transmitted from subscriber unit **14-1** to base unit **18**. Thus, base unit **18** can keep track of the antenna array settings of various subscriber units **14** in communication system **10**.

In one application, base unit **18** rather than individual subscriber units **14** determine how to set antenna parameters for directional transmissions of each of multiple subscriber units **14**. For example, based upon the lobe compare information, base unit **18** can transmit a message to the corresponding subscriber unit **14** indicating an antenna setting that is to be used for transmitting data in the reverse link. In this way, a single central tracking unit and controller located at base unit **18** can determine antenna settings for multiple subscriber units **14** to optimize a use of wireless resources of communication system **10** in which the multiple subscriber units **14** compete for the allocation of wireless resources.

Antenna devices **16** of corresponding subscriber units **14** can also operate in an omni-directional transmission mode in which information is transmitted in all or multiple directions from a corresponding antenna array. More specifically, although lobe B shows a directional lobe pattern for transmitting data, a new directional lobe setting is optionally omni-directional or multi-directional. An omni-directional, multi-directional or narrowly-directional antenna setting can then be compared to any other type of antenna array setting as previously discussed.

Notably, it can be advantageous in some applications to initially transmit information in the reverse link to base unit **18** based on an omni-directional antenna setting because it is not known in which direction to initially transmit information to base unit **18**. Thereafter, an optimal directional antenna array setting on which to transmit information can be determined using the above-mentioned method. In this way, a subscriber unit **14** initially transmitting information on a new reverse link channel can be set to transmit in an omni-directional mode until a more efficient or directional lobe is determined. Data can be transmitted in quadrants or the like until an optimal narrow beam width antenna setting is determined.

It can be determined via the use of lobe compare bit **225** that the orientation or position of a subscriber unit's **14** corresponding antenna device **16** changes frequently. In certain instances, an omni-directional antenna setting may be the most efficient setting for establishing a wireless link between a subscriber unit **14** and base unit **18**.

An omni-directional antenna setting can also be advantageously used in hard hand-offs between one base unit **18** and another. For instance, a subscriber unit **14-1** can maintain a continuous connection with a hardwired network on the ground, but via a new base station at a different location.

While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

What is claimed is:

1. A subscriber unit comprising:

an antenna array; and

an antenna array interface coupled to the antenna array;

wherein the antenna array and antenna array interface are configured to implement a method; the method comprising:

receiving, at the antenna array, wireless transmissions, at least two of which are based on different directional transmissions from a transmitter;

generating, using the antenna array interface, a first type of feedback messages to control a power output level of the transmitter;

generating, using the antenna array interface, a second type of feedback messages to indicate which of the at least two different directional transmissions from the transmitter supports a higher quality received signal;

communicating, using the antenna array, the first and second type of feedback messages over a shared feedback channel to adjust settings of the transmitter;

partitioning the shared feedback channel into multiple repeating sequences of frames; and

communicating, using the antenna array, either a first or second type of feedback message in a frame of the shared feedback channel depending on a position of the frame in a sequence of periodically repeating frames.

2. The subscriber unit as in claim **1**, wherein the antenna array and antenna array interface are further configured to implement the method further comprising:

in a first frame of the shared feedback channel, transmitting a first type of feedback message, and

in a frame contiguous with the first frame, transmitting a second type of feedback message.

3. The subscriber unit as in claim **2**, wherein the antenna array and antenna array interface are further configured to implement the method wherein at least one of the first type of feedback message or the second type of feedback message is a single bit.

4. The subscriber unit as in claim **2**, wherein the antenna array and antenna array interface are further configured to implement the method wherein the first type of feedback message is a power control bit.

5. The subscriber unit as in claim **2**, wherein the antenna array and antenna array interface are further configured to implement the method wherein the second type of feedback message is a lobe control bit.

6. The subscriber unit as in claim **1**, wherein the antenna array and antenna array interface are further configured to implement the method further comprising:

partitioning a data channel into frames in which data information is transmitted; and

for two successive frames of the data channel, generating two different directional transmissions from the transmitter.

7. The subscriber unit as in claim **6**, wherein the antenna array and antenna array interface are further configured to implement the method further comprising:

receiving a feedback message at the transmitter indicating which of the two different directional data transmissions results in a higher quality received signal.

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